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Performance Evaluation of an Improved Street Sweeper

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Performance Evaluation of an Improved Street Sweeper

by

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16. ABSTRACT The paper gives results of an evaluation of the performance of an improved street sweeper (ISS) and conventional sweepers. Dust emissions from paved roads are a major source of urban airborne particles. These emissions can be controlled by street cleaning, but commonly used sweepers were not designed for fine particle collection. A sweeper was modified to improve its ability to remove fine particles from streets and to contain its dust dispersions. Performance was measured by sampling street solids with a vacuum system before and after sweeping. Sieve analyses were made on these samples. During sampling, cascade impactor subsamples were collected to measure the finer particles. Also, dust dispersions were measured. The ISS cleaned streets much better than the other sweepers. Typically, the broom sweepers removed 0 to 45% of the street solids; the vacuum sweeper, 20 to 75%; and the ISS, 30 to 85%. Additionally, the ISS was the only sweeper tested that gave a constant, low level of residual street solids that was independent of the initial amount of street solids.

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PERFORMANCE EVALUATION OF AN IMPROVED STREET SWEEPER, M. Duncan, R. Jain, S. Yung, and R. Patterson, Air Pollution Technology, Inc., San Diego, CA 92109

Dust emissions from paved roads have been shown to be a major source of urban airborne particles. These emissions can be controlled by street cleaning, but commonly used street sweepers were not designed for fine particle collection. A street sweeper was modified to improve its abilities to remove fine particles from streets and to contain its dust dispersions. A performance evaluation of this Improved Street Sweeper (ISS) and conventional sweepers is presented. Street cleaning performance was measured by sampling street solids with a vacuum system before and after sweeping. Sieve analyses were made on these samples. During sampling, cascade impactor subsamples were collected to measure the finer particles. Also, dust dispersions were measured. The ISS cleaned streets much better than the other sweepers. Typically, the broom sweepers removed 0 to 45% of the street solids, the vacuum sweeper removed 20 to 75% of the solids, and the ISS removed 30 to 85%. Additionally, the ISS was the only sweeper tested that gave a constant, low level of residual street solids that was independent of the initial amount of street solids.

Introduction

Many metropolitan areas in the U. S. are out of compliance with the National Ambient Air Quality Standards (NAAQS) for particulate matter. A major source of this urban particulate matter is the dust emissions from paved streets. In many downtown areas, the wind- and vehicle-induced reentrainment of street dust is a large source of particulate matter. The contribution of reentrained street dust to ambient concentrations of total suspended solids is about 14 to 20 $\mu g/m^3$, which amounts to about one-third of the NAAQS secondary standard of 60 $\mu g/m^3$ (annual geometric mean).[1]

One way to reduce particle emissions from streets is to reduce the amount of street dust. The most common method for doing this is street sweeping. However, most street sweepers are not designed with fine particle removal as a priority. They have been primarily designed to remove the trash and larger solids, to make the streets look clean. In addition, most street sweepers disperse some of the street dust into the air during sweeping.

The potential for reducing the particle emissions from streets by cleaning is great. For example, Roberts[2] found that cleaning a dirty paved road could reduce particle emissions by more than 80%.

To address this large potential for reducing airborne particles, Air Pollution Technology, Inc., developed an Improved Street Sweeper (ISS) under contract with the Industrial Environmental Research Laboratory-RTP of the U.S. EPA. Under the development contract, A.P.T. performed an experimental program to develop modifications for improving the ability of municipal street sweepers to remove inhalable dust particles from urban streets, and for containing the particle dispersions of these sweepers.

The ISS was subjected to a limited testing program in San Diego and Los Angeles during the development contract. Results clearly indicated that the ISS can eliminate the dust plume during sweeping and give a cleaner street. However, additional research work was needed to demonstrate its capability.

This paper documents the methodologies and results of a follow-up EPA contract for evaluating the ISS performance. For this evaluation, extensive tests were conducted to determine the improved street cleaning performance and the effectiveness for reducing fugitive particle emissions. The ISS was evaluated along with conventional sweepers in Bellevue, WA, and in San Diego, CA. The tests done in Bellevue were performed cooperatively with the City of Bellevue, which studied the effect of street sweeping on urban runoff quality (under contract with the Municipal Environmental Research Laboratory of the U.S. EPA).

Evaluation Objectives

The objectives for this evaluation were as follows:

1. Compare the street cleaning abilities of the following street sweepers:
   a. A.P.T. ISS
   b. Tymco Model 600 regenerative air sweeper
   c. Mobil broom sweeper
   d. FMC broom sweeper
2. Compare the dust dispersions of the ISS and the Tymco sweepers.
3. Determine particle emissions from the ISS scrubber.

Street Sweeper Descriptions

Street sweepers can be categorized into two major groups according to the mechanism that they use to pick up solids from the street. These two groups are broom sweepers and vacuum sweepers. (A third, smaller group is vacuum-assisted broom sweepers.) The ISS is a vacuum sweeper with equipment added by A.P.T. for performance improvement. Descriptions of the four sweeper types used in this study are given below.

Mobil Sweepers

The Mobil sweepers are four-wheeled broom sweepers. They use a rotating gutter broom to move the dirt from the area of the street near the curb to the portion of the street under the sweeper. A center rubber strip stops the dirt from over-shooting the center of the sweeper. From there, the dirt is swept onto a squeegee-type dirt elevator by a large, cylindrical pickup broom that rotates about a horizontal shaft at the rear of the sweeper. The dirt elevator lifts the dirt into a collection hopper. Across the front of the sweeper, and at the gutter broom, water sprays are used to suppress dust dispersions during sweeping.

FMC Sweepers

The FMC sweepers are similar to the Mobil sweepers described above. The major difference is in the gutter broom arrangement. The FMCs have two brooms of smaller diameter at the gutter, rather than one as on the Mobil sweepers. One broom moves the dirt from the gutter, and the second broom, located inside and behind the first broom, moves the dirt the rest of the distance to the area in front of the pickup broom.

Tymco Sweeper

A Tymco regenerative-air vacuum sweeper, which was modified to the ISS, was used in the unmodified mode for baseline tests. This sweeper uses a regenerative air system for dust pickup. A gutter broom moves the street debris from the curb toward the center of the sweeper where there is a rubber backstop strip. A blower forces air through a hose to a blast orifice slot of a pickup head, creating a full width, high velocity blast that loosens debris from the street. The pickup head has rubber curtains at its leading and trailing edges to seal against the street. The head rides on its metal side edges. The blower establishes vacuum in the pickup head which sucks up the debris through a hose into a hopper, where the air loses velocity, and heavy or large debris falls to the hopper floor. The air is drawn through a screen to remove paper and leaves, and then enters a centrifugal separator where large dust particles are collected and thrown into the hopper. The air is then drawn into the blower to start another cycle. To suppress dust clouds, the Tymco has three water spray nozzles at each end of the pickup head, three at each gutter broom, and four inside the hopper.

A.P.T. Improved Street Sweeper

The ISS is the Tymco sweeper described above with some modifications. The primary objective of the modifications was to maximize the collection of fine particles. Observations made during sweeping revealed that the gutter broom dust plume and dust leakage from the pickup head were the major sources of fugitive dust emissions from the Tymco sweeper.

The dust clouds around each gutter broom were controlled with a partial hood and ducting to the hopper. The hood has a suction slot and a rubber impaction flap around the outside of the hood. The dirt moved by the gutter broom impacts against the rubber flap. Plumes of the fine particles form as they separate from the coarser particles and are sucked up by the hood. The intake slot of the hood and the manifold are shaped to produce a uniform, high velocity in the slot (approximately 30 m/s (100 ft/s)).

The other major source of fugitive dust emissions is the pickup head. These emissions occur when uneven street surfaces are swept and the pickup head does not seal well against the street. These pickup head emissions were greatly reduced by venting air out of the regenerative air system through a leaf bleeder valve (which is opened for picking up leaves with the Tymco) and a particle scrubber. This venting causes a net inflow into the pickup head through its perimeter at the street surface.

The dusty vented air is cleaned with a wet scrubber before it is discharged into the ambient air. A preformed spray scrubber was originally installed on the ISS during the development contract. It was converted to a venturi scrubber at the

beginning of this study, because the relatively small spray scrubber had large losses of water drops on the walls.

The overall functional relationships of the ISS components are shown in Figure 1. Most of the air flow recirculates through the pickup head, hopper, and fan. In addition, air enters the system through the gutter broom hoods (0.17 m^3/s (350 cfm) at each hood) and the pickup head. It is balanced by the air (0.47 m^3/s (1000 cfm)) that exits through the scrubber via the leaf bleeder valve.

A side view of the ISS is illustrated in Figure 2. The long lengths of duct upstream and downstream of the scrubber were included to allow representative sampling during testing for collection efficiency. Also, the scrubber is mounted on top of the sweeper to allow easy access during sampling; however, on a mass-produced version of the ISS, the scrubber could be inside the hopper, and the long ducting would not be needed. The trailer in Figure 2 carries sampling equipment and is not needed for the operation of the ISS.

Test Methods

Four sweeper performance parameters were measured in this study: the ability of a street sweeper to remove solids from a street surface, the relative dust dispersions of the ISS and the Tymco sweepers, and the mass rate and size-distribution of the ISS scrubber emissions. The measurement methods are described below.

Street Solids Removal

The ability of a street sweeper to remove solids from a street was measured by sampling street solids from test sections of street before and after sweeping. Each test was performed on a test section of street, that was from 160 to 320 m (0.1 to 0.2 mi.) long. The width of each test section was from the street centerline to the curb, on only one side of the street. Each test involved only one sweeper, making one sweeping pass next to the curb (this is the usual municipal street sweeping method).

Each street dust sample was taken by vacuuming 5 to 60 randomly selected strips (the number depending upon visual observation of the dirtiness of the street). For each test, care was taken not to locate strips where previous strips were sampled. Two types of samples were taken: half-of-street strips from the curb to the centerline, and strips in the sweeping lane.

The common term for expressing the amount of solids on a street is weight per curb-length. This commonly includes the solids on the street that are between the curb and the centerline of the street; that is, the solids of half of the street are associated with each curb. Consequently, the half-of-street samples were used to express sweeper performance relative to this

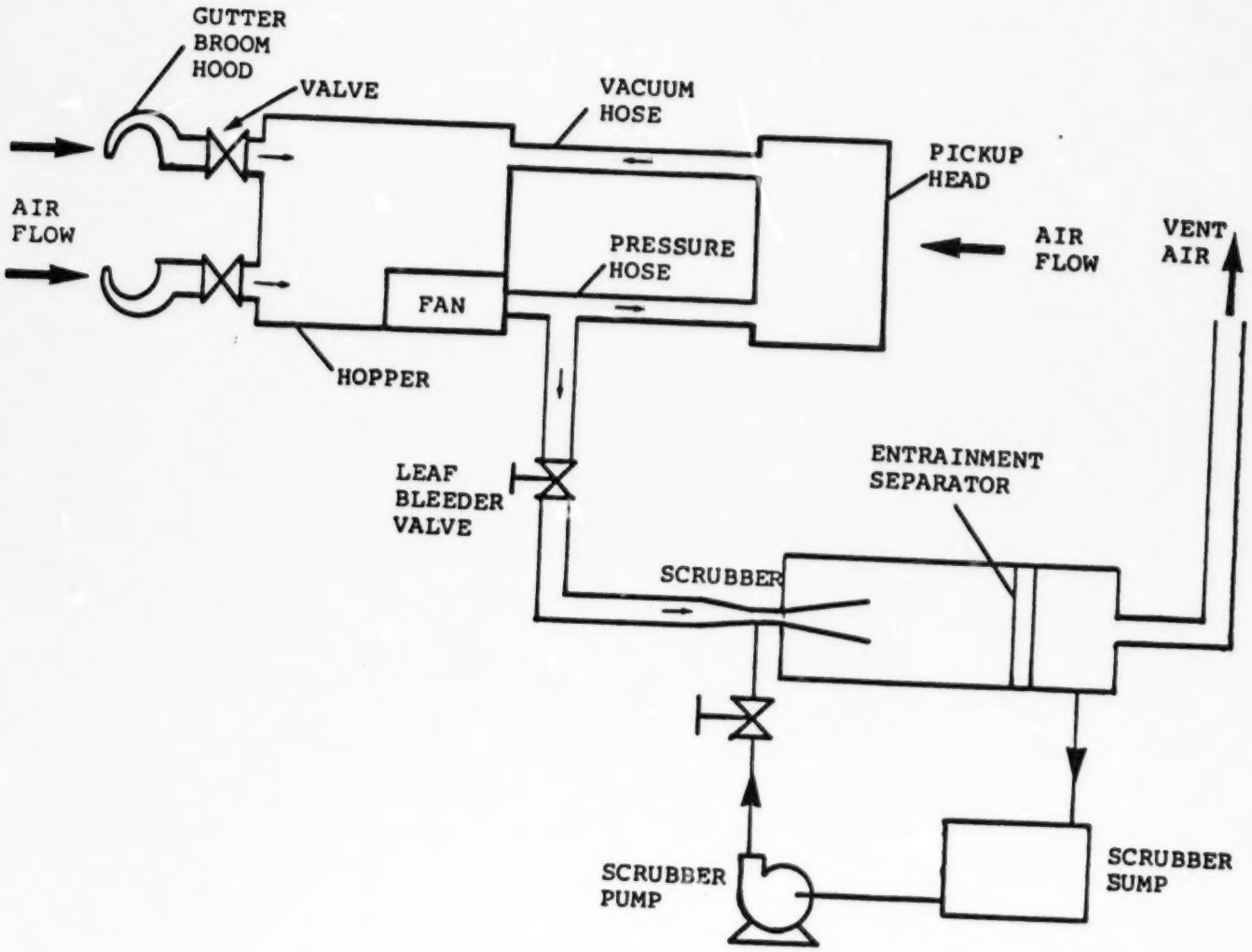

Figure 1. Process diagram of ISS.

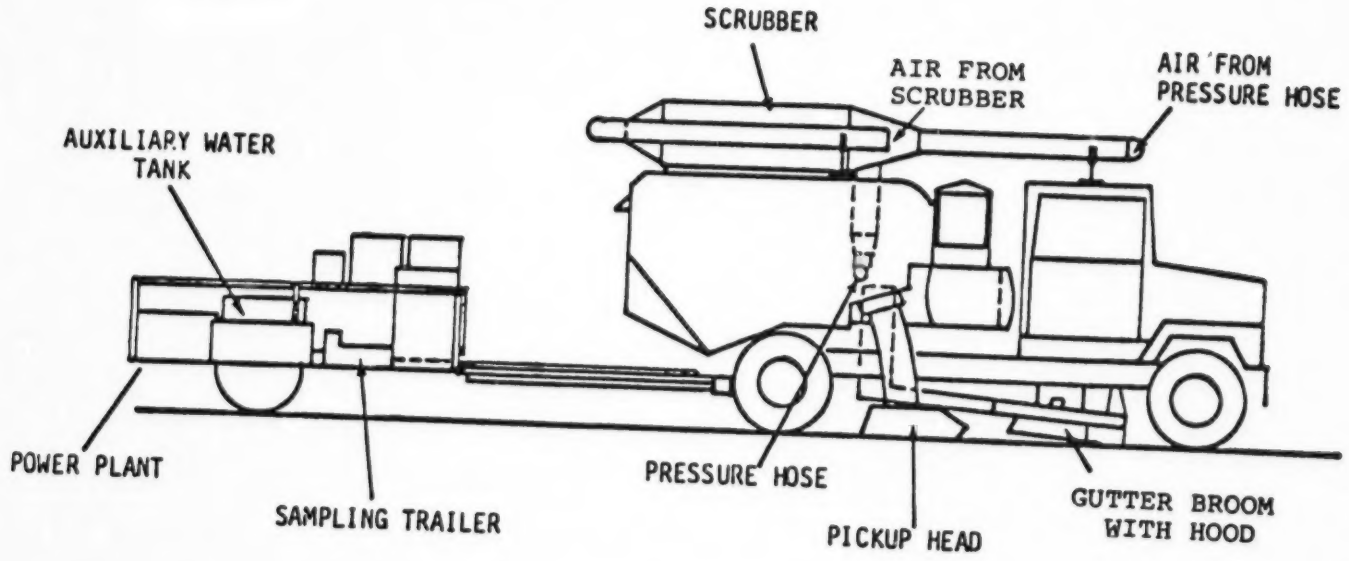

Figure 2. ISS and sampling trailer.

commonly accepted measure of street solids. In other words, the half-of-street samples indicate how much of all of the solids on the street are removed.

The sweeping lane samples were taken to determine how well a sweeper removes the solids in its path. The sweeping lane samples taken after sweeping indicate how much solids the sweeper was unable to pick up. Whereas, the half-of-street samples taken after sweeping only indicate the sum of the left-behind solids and the solids outside the path of the sweeper. Thus, the sweeping lane samples provide a closer, more accurate measure of sweeper performance than the half-of-street samples.

In any case where a sweeper moves some solids from the swept lane to the unswept portion of the street, comparison of the half-of-street and sweeping lane samples will reveal this. Also, comparison of the two types of samples will indicate how much of the solids are outside the sweeping lane. This could aid decisions concerning how much of the street width to sweep.

The dirt vacuumed from the street was collected in a vacuum cleaner cannister, and the vacuum cleaner air was filtered by a pair of cloth filters in the cannister. The cannister samples were sized by sieve analysis. The Bellevue samples were analyzed with these sieve sizes: 6300, 2000, 1000, 500, 250, 125, 63, and 37 μm. The San Diego samples were analyzed with these sieve sizes: 5600, 2000, 500, 125, 63, and 38 μm. The particles smaller than 15 μmA (micrometers-aerodynamic) were sized with cascade impactor samples that were withdrawn from the vacuum cleaner system during vacuuming.

Dust Dispersion of ISS and Tymco

As a sweeper operates, dust is dispersed at the gutter broom and the pickup broom or head. The dispersed dust of the Tymco and the ISS were sampled with filters mounted in fixed positions on the sweeper. Two glass-fiber filters were mounted on the top of the pickup head at its leading edge. The two filters were 15 cm (6 in.) and 76 cm (30 in.) from the curbside end of the pickup head. Each filter was operated at a flowrate of 28 l/min (1 cfm) that was controlled and measured by an EPA Method 5 sampling train located in the sampling trailer.

Since the volumes of the dust plumes are unknown, the measured dust concentrations allow only relative comparisons of the dust dispersion.

ISS Scrubber Emission

The mass emission rate and the size distribution of the particles emitted by the ISS scrubber were determined by sampling the outlet of the scrubber with a cascade impactor. The gas sample flow rate was monitored and regulated with an EPA Method 5 sampling train located in the sampling trailer.

Results

Test Areas and Sweepers

In Bellevue, WA, street sweepers were evaluated in two areas: SE 30th St. and Surrey Downs. SE 30th St. is a 13.6 m (44.5 ft) wide, dead-ended street of a light-industrial park. The experiments in the Surrey Downs area were made on two similar streets in the same residential neighborhood. The widths of the two streets were 9.1 and 9.8 m (30 and 32 ft). All of the streets of the Bellevue test areas were asphaltic concrete and had vertical, Portland-cement-concrete curbs. All of these streets had only two traffic lanes.

At both Bellevue areas, three types of sweepers were tested: two Mobil broom sweepers, the Tymco vacuum sweeper, and the ISS. The Tymco sweeper was actually the ISS with the gutter broom hoods removed and the air flows from the hoods and to the scrubber shut off. A total of 29 tests were made in Bellevue during September and October of 1982.

The areas for the San Diego tests were on Mission Blvd. and Morena Blvd. Mission Blvd., between San Fernando Place and West Mission Bay Drive, is in a neighborhood that is commercial, residential, and recreational (beach parks). Mission Blvd. has four traffic lanes and a curbed island median. From median curb to sidewalk curb the distance was 8.5 to 9.8 m (28 to 32 ft). The half of street samples at Mission Blvd. were taken from the sidewalk curb to the paint stripe between the two traffic lanes; that is, the strip sampled one parking lane and one traffic lane. This was done to avoid sampling the dirt near the median curb, and to allow direct comparison of Mission Blvd. results with those of the other test areas. The width of this sample strip was 5.3 to 6.5 m (17.4 to 21.4 ft).

Morena Blvd., between Jutland Drive and Ariane Drive, is in a commercial area, has two traffic lanes, and is 15.2 m (50 ft) wide. During the tests there was an inactive, partially completed construction site immediately adjacent to the test sections. Both San Diego streets were asphaltic concrete and had vertical, Portland-cement-concrete curbs.

Along with the Tymco and the ISS, Mobil and FMC broom sweepers of the City of San Diego were tested. All four sweeper types were tested at Mission Blvd. At Morena Blvd., the City of San Diego did not use Mobil sweepers, so only FMC sweepers, the Tymco sweeper, and the ISS were tested. A total of 28 tests were made in San Diego during January, February, August, and September of 1983.

Description of Street Solids

Comparison of the initial half-of-street and sweeping lane samples revealed that 70 to 100% of the street solids were within

the sweeping lane. This distribution of street dust agrees with two measurements reported by the City of Bellevue. They found that: 45 to 55% of the solids were within 0.51 m (1.7 ft) of the curb, 75 to 80% were within 1.2 m (4.0 ft) of the curb, and 85 to 95% were within 2.4 m (8.0 ft) of the curb.

For the four test areas of this study, typical mass median diameters of the street solids varied from 200 to 500 μm. The particles of Surrey Downs were the coarsest, probably because Surrey Downs is a residential area and has less traffic to pulverize the street dust.

Street Cleaning Performance

The street cleaning performance of a street sweeper depends on the following major parameters: the amount of solids on the street, the size distribution of the solids, street surface characteristics (such as texture, amount of cracking, depth of cracks), and the capabilities of the sweeping machine.

To accommodate the dependence upon the amount of solids, graphs of the residual loading of solids versus the initial loading of solids were used to describe street sweeper performance in this study. The influence of the size of the solids was investigated by performance graphs for various ranges of particle sizes (in addition to graphs for the total street solids). To eliminate the effects of street surface characteristics, each graph was for only one test area.

The presentation of sweeper performance in terms of removal efficiency as a function of particle size was considered. However, this method was found to be not suitable, because the removal efficiency strongly depends on the amount of solids on the street.

Some typical performances of the sweepers for total solids (all particle sizes), based on the half-of-street samples, are shown in Figure 3. Depending on the initial street dust loading, the broom sweepers removed 0 to 40 % of the solids, while the ISS removed 30 to 60% of the solids. The Tymco sweeper was slightly less effective than the ISS, but was more effective than the broom sweepers.

Some typical sweeper performances for total solids, based on the sweeping lane samples, are shown in Figure 4. The sweeping-lane performances revealed larger differences between the sweepers than the half-of-street graphs, because the solids of the unswept area are not included in the residuals (as discussed earlier). The broom sweepers removed approximately 5 to 45 % of the solids, and their performance curves usually have slopes of approximately 1. The Tymco removed approximately 50 to 75 % of the solids, and its performance curve slopes are about 0.25. The ISS removed 50 to 85 % of the solids, and its curves have slopes of zero. This indicates that the ISS gives a constant residual

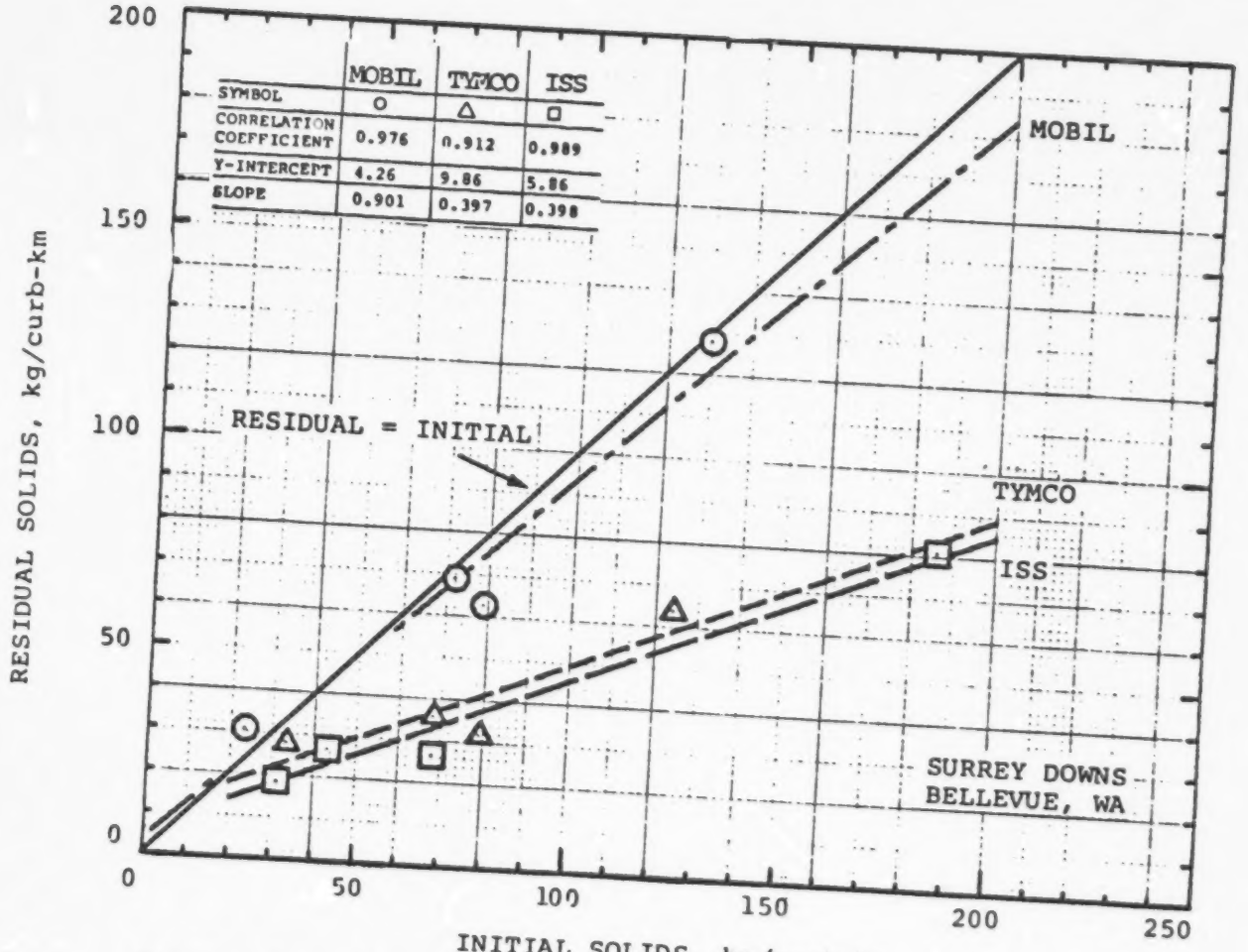

Figure 3. Total solids performance at Surrey Downs from half-of-street samples.

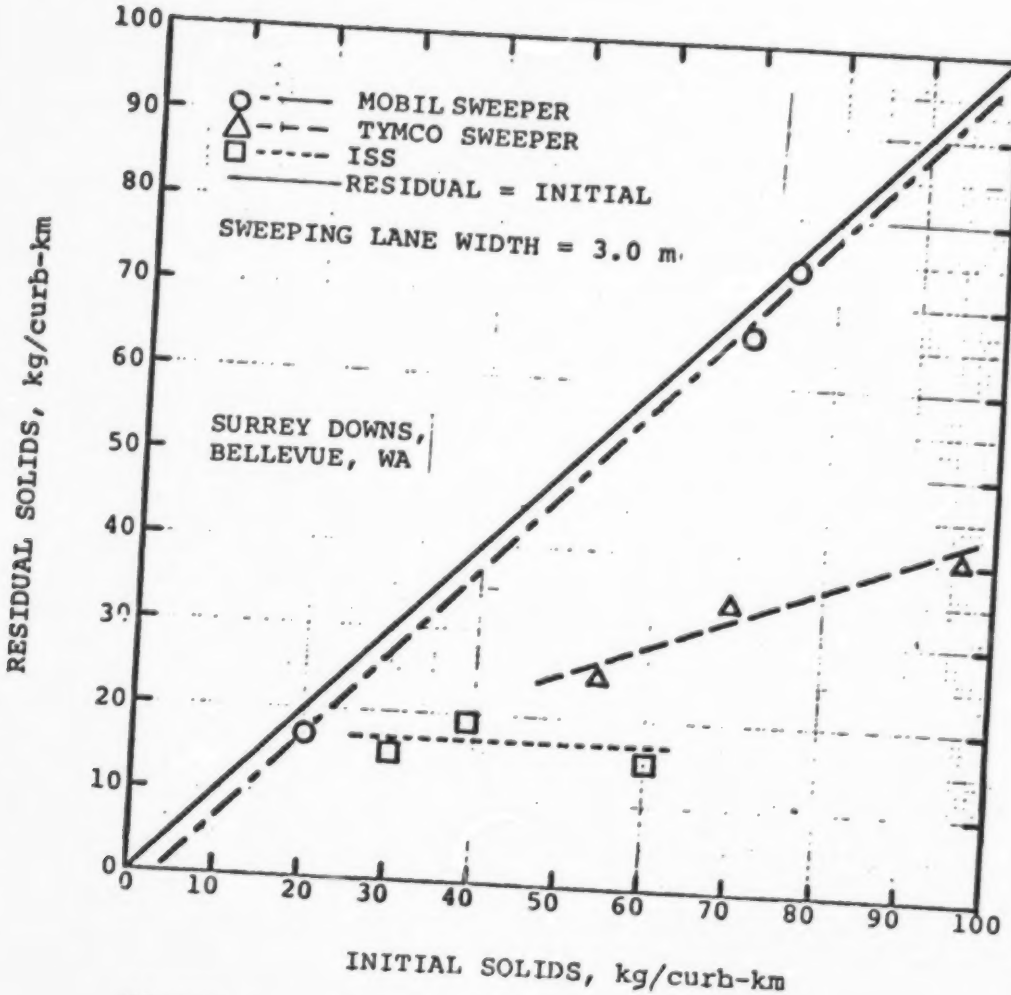

Figure 4. Total solids performance at Surrey Downs from sweeping lane samples.

level that is independent of the amount of initial street solids. Figure 5 shows a set of 90% confidence regions for performance from least-squares, linear regressions of the data.

Street cleaning performances for these ranges of particle sizes were investigated: larger than 2000 μm, from 500 to 2000 μm, from 63 to 500 μm, smaller than 63 μm, and smaller than 10 μmA. The trends of these performances were similar to those for total solids.

Dust Dispersion of ISS and Tymco

The mass concentrations of dust measured at the pickup head of the ISS and the Tymco were plotted versus the initial sweeping lane solids smaller than 10 μmA. The data points were very scattered. Therefore, it cannot be concluded that the ISS disperses less dust than the Tymco. However, based on visual observations, the ISS did have smaller dust plumes than the Tymco.

ISS Scrubber Emissions

The mass median diameter of the particles in the ISS scrubber exhaust was about 2 μmA, and 94% of the emissions were smaller than 10 μmA. The mass emission rate of the ISS scrubber is plotted along with residual solids smaller than 10 μmA in Figure 6. Most of the emission rates were between 2 and 40% of the initial solids smaller than 10 μmA.

Conclusions

The results of this study show that the ISS removes more street solids than the same sweeper without the improvements for all particle-size fractions. It also removes much more of the street solids than the widely used broom sweepers. Typically, a broom sweeper removes 0 to 45% of the street solids, the Tymco sweeper removes 20 to 75%, and the ISS removes 30 to 85%. Additionally, the ISS was the only sweeper tested that gave a constant, low level of residual street solids that was independent of the initial amount of solids on the street. However, the residual level does depend on the street surface characteristics.

Based on visual observations, the ISS dispersed less dust during sweeping. However, the data from measurements of the dust concentration at the pickup head of the Tymco and the ISS were too scattered to allow statistical verification.

The particle mass emission from the scrubber on the ISS was from about 2 to 40% of the initial street solids smaller than 10 μmA. The mass median diameter of the emissions was 2 μmA.

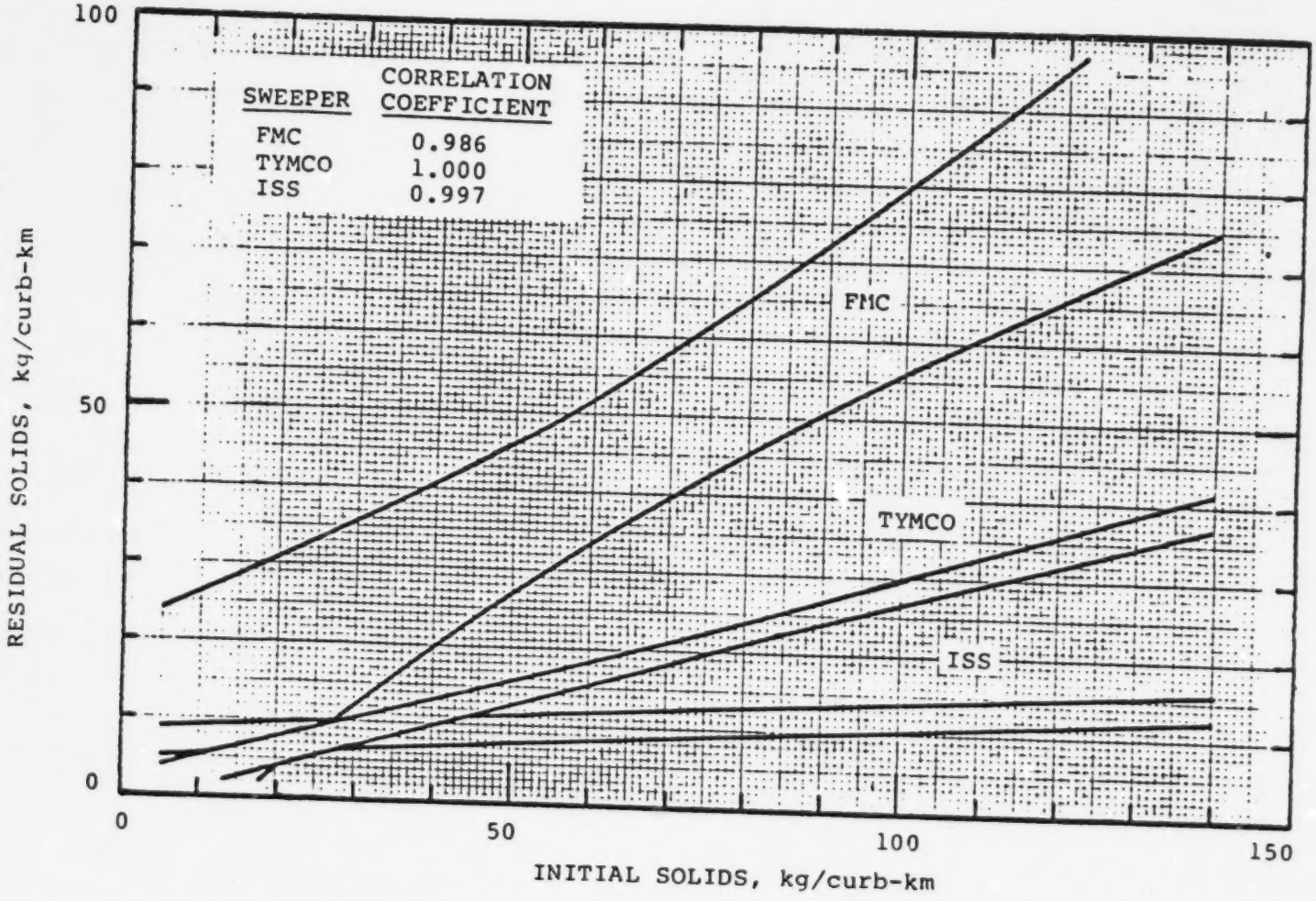

Figure 5. 90% confidence regions of the total solids performance at Morena Blvd., from sweeping lane samples.

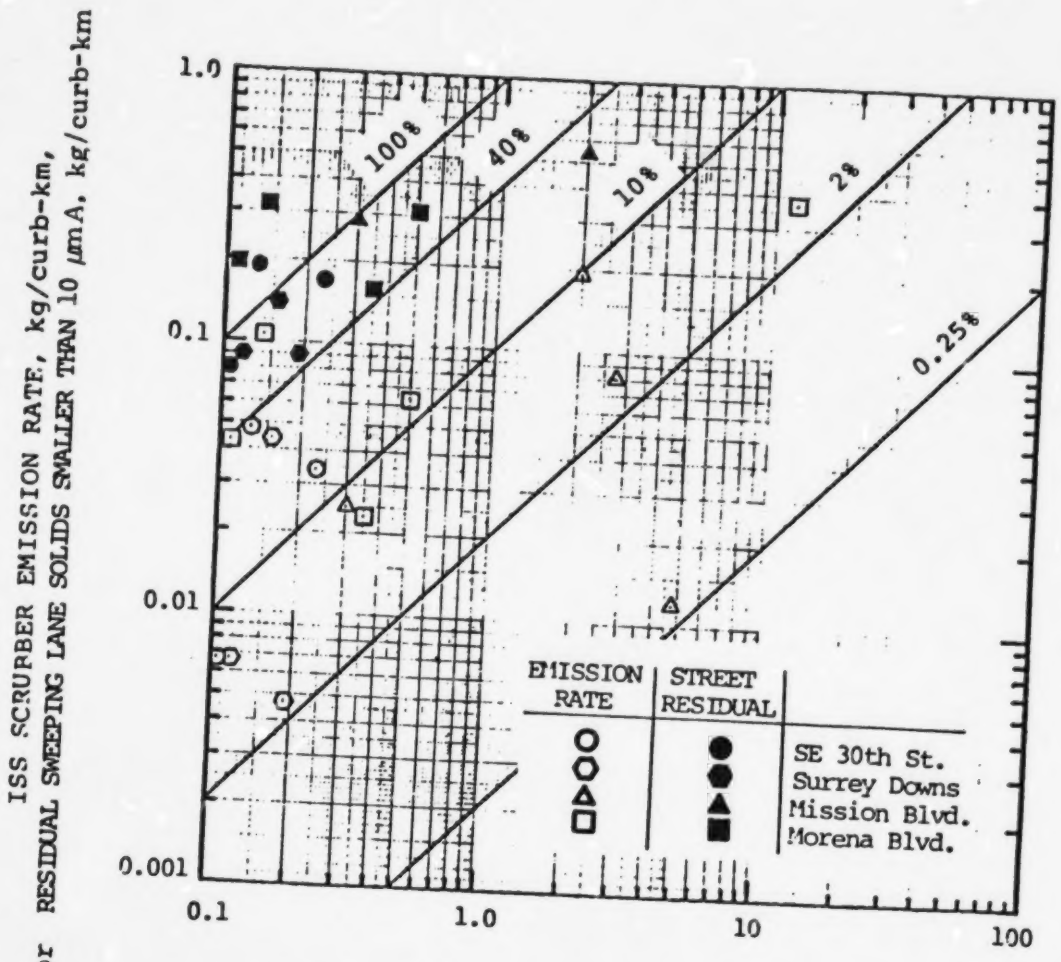

Figure 6. ISS scrubber emissions and initial and residual street solids.

This evaluation shows that the ISS cleans streets much better than conventional sweepers. However, its effects on ambient air quality have not been measured. To complete the evaluation of the ISS, the emission factors of the ISS and conventional sweepers need to be measured. This could be accomplished by sampling ambient air upwind and downwind of streets during and between sweepings.

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